Amendments to the Specification:

Please replace paragraphs **[0014], [0015], [0016], [0018], [0019], [0020], [0021], [0022], [0023], [0024], [0027], [0028], [0029], [0030], [0032], [0033], [0034], [0035], [0037], [0039], [0040], [0041], [0042], [0047], [0049], [0054], [0056], and [0063]** with the following amended paragraphs:

[0014] Another cooling method for deep-well cooling uses ~~an active~~ a water vaporization cooling system to cool electronics in a downhole tool. In this method, water in one tank is ~~in thermal contact~~ thermally connected with the electronics chassis of the downhole tool. The water absorbs heat from the downhole environment and the electronics and begins to vaporize at 100°C so long as the pressure of the tank is maintained at 1.01×10^5 Pa (14.7 psi). In order to maintain the pressure, the steam is removed from the tank and compressed in a second tank. However, sufficient steam must be removed from the first tank in order to maintain the pressure at 1.01×10^5 Pa. Otherwise, the boiling point of the water will rise and thus raise the temperature of the electronics chassis in the first tank.

[0015] In practice, ~~active~~ steam cooling has significant problems. First, ~~this method has very large compression requirements because the compressed steam in the second tank cools to the temperature of the downhole environment. The~~ a compressor must be supplied that is able to compress the steam to a pressure greater than the saturation pressure of steam at the temperature of the downhole environment, which is 1.55×10^6 Pa (225 psi) at 200°C. Second, this method is also time limited based on the amount of water in the first tank because when all the water in the first tank vaporizes, the cooling system will not function. In addition, the method does not isolate the electronic components but instead attempts to cool the entire electronics region. While the temperature of the region may remain at 100°C, the temperature of the discrete electronic components ~~will~~ may be higher because they ~~are~~ may internally ~~generating~~ generate heat. Consequently, this system does not effectively maintain the temperature of the discrete electronic components in order to minimize the effects of thermal failure.

[0016] Another cooling method attempts to resolve the problem of the high compression requirements of the above-mentioned cooling system by use of a sorbent cooling system. This method again uses the evaporation of a liquid that is ~~in thermal contact~~ thermally connected with the electronic

components to maintain the temperature of the components. Instead of using a compressor to remove the vapor, this method uses desiccants in the second tank to absorb the vapor as it evaporates in the first tank. However, the desiccants must absorb sufficient vapor in order to maintain a constant pressure in the first tank. Otherwise, the boiling point of the liquid will rise as the pressure in the lower tank rises.

[0018] Other methods also cool electronics apart from downhole applications. For example, micro-channel heat exchangers cool microprocessors and other microelectronic devices in surface-based applications. However, these systems operate in an environment where the ambient temperature is less than the device being cooled. In a downhole environment, the ambient temperature is often higher than the ~~electronic~~ recommended operating temperature of the components being cooled. These methods will not function properly in a downhole environment because they cannot remove the heat from the ~~coolant~~ components in an environment where the ambient temperature is higher than that of the ~~heated coolant~~ components.

[0019] None of the known cooling methods effectively and efficiently controls the temperature of electronic components in downhole tools. An effective cooling system for electronic components in downhole tools is one that performs ~~either~~ at least one or both of the following: (1) isolates thermally sensitive components from the environment; and (2) removes heat from thermally sensitive components. Consequently, to effectively manage the temperature of discrete thermal components in downhole tools, the present invention has been developed. Other objects and advantages of the invention will appear from the following description.

[0020] The temperature management system manages the temperature of ~~discrete~~ one or more thermal components ~~in cavities~~ in downhole tools, such as those suspended on a drill string or a wireline. The temperature management system comprises a heat exchanger ~~in thermal contact~~ thermally coupled with the thermal component, or thermally coupled with a chassis of thermal components. The temperature management system also comprises a heat sink ~~comprising a phase change material~~. A thermal conduit system ~~connects~~ thermally couples the heat exchanger and heat sink ~~in thermal communication~~. The thermal conduit system transfers heat absorbed by the heat

exchanger from the one or more thermal ~~component~~ components to the heat sink. The heat sink may in turn ~~absorbs~~ absorb the heat from the thermal conduit ~~as it changes phase~~ or directly from the one or more thermal components. A second, different heat exchanger coupled to the heat sink may be utilized to efficiently transfer heat from the thermal conduit. The heat sink may be disposed locally to the thermal component, or may be remotely disposed, *e.g.*, the heat sink may be in the same cavity as the one or more thermal components, or may be located external to the thermal component cavity. The temperature management system is thus able to discretely manage the temperature of thermal components inside a cavity instead of managing the temperature of the cavity as a whole.

[0021] In another embodiment of the invention, the thermal conduit system comprises a closed loop, coolant fluid conduit system. A fluid transfer device circulates coolant fluid through the conduit system. As the coolant fluid circulates through the thermal conduit system, the coolant flows through the heat exchanger, absorbing heat from the heat exchanger and enabling the heat exchanger to absorb more heat from the thermal component. After exiting the heat exchanger coupled to the thermal component(s), the heated coolant fluid flows to the heat sink ~~where~~ wherein the heat sink absorbs heat from the coolant, thus enabling the coolant to absorb more heat from the ~~heat exchanger~~ one or more thermal components. After exiting the heat sink, the coolant fluid ~~again circulates~~ may circulate through the temperature management system.

[0022] ~~Alternatively~~ In one embodiment of the invention, the temperature management system may comprise an open loop, coolant fluid conduit system. Instead of re-circulating coolant fluid through the fluid conduit system, the temperature management system ~~expels~~ may store or even expel the coolant fluid after the coolant fluid flows through the heat exchanger and the heat sink.

[0023] In another embodiment of the invention, ~~there are~~ for multiple thermal components, each thermal component or group of components ~~requiring~~ may require a separate heat exchanger. To accommodate the multiple heat exchangers, the thermal conduit system comprises thermal conduit branches that branch out to each heat exchanger and then ~~join back together~~ rejoin or recombine for flow of the coolant fluid to the heat sink. The multiple heat exchangers may be arranged in series, in parallel, or any combination of series and/or parallel. Alternatively, the temperature management

system may further ~~comprises~~ comprise valves for controlling fluid flow through each thermal conduit branch if the conduit system is a coolant fluid conduit system. The valves can control the flow through the thermal conduit branches to isolate particular heat exchangers from the temperature management system when the cooling of that component or group of components is not necessary.

[0024] In another embodiment of the invention, the temperature management system comprises a thermal barrier to the downhole environment. The thermal barrier acts to hinder heat transfer from the downhole environment to the thermal components. Such a barrier may be an insulated vacuum "flask" or any other suitable barrier that thermally isolates at least the one or more thermal components and/or components of the temperature management system described above.

[0027] The present invention relates to a thermal component temperature management system and includes embodiments of different forms. The drawings and the description below disclose specific embodiments of the present invention with the understanding that the embodiments are to be considered an exemplification of the principles of the invention, and are not intended to limit the invention to that illustrated and described. Further, it is to be fully recognized that the different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce desired results. The term "couple", "couples", or "thermally coupled" used herein is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, *e.g.*, via conduction though one or more devices, or through an indirect connection; *e.g.*, via convection or radiation.

[0028] FIGURE 1 ~~shows~~ illustrates a temperature management system 10 disposed in a downhole tool 14 such as on a drill string 16 for drilling a borehole 13 in a formation 17. The temperature management system 10 might also be used in a downhole wireline tool, a permanently installed downhole tool, or a temporary well testing tool. Downhole, the ambient temperature can be extremely thermally harsh, sometimes exceeding 200°C. However, the temperature management system 10 may also be used in other situations and applications where the surrounding environment ambient temperature is either greater than or less than that of the thermal components being cooled.

[0029] The temperature management system 10 discretely manages the temperature of a thermal component 12 mounted on a board 18 in the downhole tool 14. The thermal component 12 comprises, but is not limited to, heat-dissipating components, heat-generating components, and/or heat-sensitive components. An example of a thermal component 12 ~~is a heat-generating~~ may be an integrated circuit, *e.g.*, a computer chip, or other electrical or mechanical device that is heat-sensitive, or whose performance is deteriorated by high temperature operation, or a device that generates heat. The board 18 is in turn mounted on a chassis (not shown) and installed within a cavity 15 of the tool 14. The temperature management system 10 further comprises a heat exchanger 20 ~~in thermal communication~~ thermally coupled with the thermal component 12. ~~The~~ In one embodiment of the invention, the heat exchanger 20 is ~~in direct thermal contact with~~ thermally coupled via a conductive path to the thermal component 12. However, in other embodiments of the inventions the heat exchanger 20 may ~~also~~ be ~~in indirect thermal contact~~ thermally coupled with the thermal component 12 by radiation or convection. The heat exchanger 20 may be any appropriate type of heat exchanger ~~such as~~, *e.g.*, a conduction heat exchanger that uses heat conduction to transfer the heat through solids. The heat exchanger 20 may also comprise multiple layers of the same or different materials.

[0030] The temperature management system 10 also comprises a heat sink 22 preferably comprising a phase change material. Phase change material is designed to take advantage of the heat absorbed during the phase change at certain temperature ranges. For example, the phase change material may be a eutectic material. Eutectic material is an alloy having a component composition designed to achieve a desired melting point for the material. The desired melting point takes advantage of latent heat of fusion to absorb energy. Latent heat is the energy absorbed by the material as it changes phase from solid into liquid. Thus, when the material changes its physical state, it absorbs energy without a change in the temperature of the material. Therefore, additional heat will only change the phase of the material, not its temperature. To take advantage of the latent heat of fusion, the eutectic material ~~would~~ may have a melting point ~~below the boiling point of water and~~ below the desired maintenance temperature of the thermal component 12.

[0032] The heat exchanger 20 and heat sink 22 are ~~in thermal communication~~ thermally coupled via a thermal conduit system 26. The thermal conduit system 26 comprises a thermally conductive

material for transferring heat from the heat exchanger 20 to the heat sink 22. The thermal conduit system 26 may connect to the heat exchanger 20 and the heat sink 22 by any suitable means such as welding joints or threaded connections.

[0033] The temperature gradient between thermal component 12 and the heat sink 22 is such that the heat sink 22 absorbs the heat from the thermal component 12 through the heat exchanger 20 and the thermal conduit system 26. The temperature management system 10 removes enough heat to maintain the thermal component 12 at or below its rated temperature, which ~~is typically no more than~~ may be *e.g.* 125°C. ~~For example,~~ In one embodiment of the invention, the temperature management system 10 may maintain the component 12 at or below 100°C, or even at or below 80°C. ~~The~~ Typically, the lower the temperature, the longer the life of the thermal component 12.

[0034] Thus, the temperature management system 10 ~~does not absorb heat from~~ may not manage the temperature of the entire cavity 15 or even the entire electronics chassis, but ~~only~~ does manage the temperature of the thermal component 12 itself. When absorbing heat discretely from the thermal component 12, the temperature management system 10 may allow the ~~general~~ temperature of the cavity 15 to reach a higher temperature than ~~prior art cooling systems~~ that of the thermal components. ~~However, even though the temperature of the cavity 15 may be higher, the temperature of the thermal component 12 will be lower than prior art cooling system components.~~ Absorbing heat discretely from the thermal component 12 thus extends the useful life of the thermal component 12 ~~as compared to prior art cooling systems~~, despite the temperature of the cavity 15 being higher. This allows the thermal component to operate a longer duration at a given temperature for a given volume of heat sink than possible if the temperature of the entire cavity is managed.

[0035] Because the temperature of the downhole environment may be greater than the temperature of the heat sink 22, in one embodiment of the invention, the heat removed from the thermal component 12 and transmitted by the thermal conduit 26 is stored in the heat sink 22. In other embodiments of the invention, the heat removed from the thermal component 12 may be absorbed directly by the heat sink 22; *e.g.*, via conduction by being in contact with the heat exchanger, or the heat may be absorbed by the heat sink via convection or radiation from the heat exchanger. Consequently, the amount of heat

the heat sink 22 can absorb from the thermal component 12 limits the temperature management system 10. When the heat sink 22 reaches its heat storage capacity, the downhole tool 14 is brought up closer to the surface or removed from the well 13 and the heat stored in the heat sink 22 dissipates into the cooler environment.

[0037] Unlike the temperature management system 10, the heat exchanger 220 in the temperature management system 210 is a micro-capillary heat exchanger. ~~The~~ In one embodiment, the micro-capillary heat exchanger 220 is a micro-channel, cold plate heat exchanger with stacked plates 220a enclosed in a housing 220b shown in FIGURE 3. The housing 220b includes inlet port 220c and outlet port 220d. To reduce the pressure drop through the micro-capillary exchanger 220, the plates 220a of the exchanger 220 ~~are~~ may be stacked as shown in FIGURE 3. The number of stacked plates 220a may be varied to optimize pressure drop, heat transfer, and other characteristics. In addition, the plates 220a of the micro-capillary exchanger 220 may be of any suitable material, such as copper or silicon.

[0039] ~~Located~~ In one embodiment of the invention, located in the thermal conduit system 226 is a fluid transfer device 228 for flowing the coolant fluid through the thermal conduit system 226. The fluid transfer device 228 may be any suitable device for flowing the coolant fluid. By way of non-limiting example, the fluid transfer device may be a pump, such as a mini-pump or a micro-pump. The fluid transfer device 228 may be located at any suitable location in the thermal conduit system 226. In addition, the fluid transfer device 228 may also circulate the coolant fluid in either flow direction. In other embodiments of the invention, the fluid in the thermal conduit system 226 flows via convection; *e.g.*, by maintaining a temperature differential between any two points in the system.

[0040] The coolant fluid flowing within the thermal conduit system 226 is a coolant fluid ~~in thermal communication~~ that may be thermally coupled with the heat exchanger 220 and the heat sink 222. The coolant fluid may be water or any other suitable fluid. The temperature management system 210 ~~is~~ may be a single-phase temperature management system. Thus, the coolant is a liquid and does not undergo a phase change while it circulates through the temperature management system 210. Alternatively, the temperature management system 210 may be a two-phase system where the coolant fluid changes to a gas phase and then back to the fluid phase as it cycles through the temperature

management system 210. The two-phase system coolant fluid absorbs heat as it changes from the liquid to the gas phase and releases heat as it changes from the gas to the liquid phase.

[0041] In operation, the coolant travels from the fluid transfer device 228 to the heat exchanger 220 where the coolant is ~~in thermal communication~~ thermally coupled with the heat exchanger 220. The coolant passes into the inlet port 220c of the heat exchanger 220 and flows through the stacked plates 220a. As the coolant flows through the heat exchanger 220, it absorbs heat from the heat exchanger 220, thus allowing the heat exchanger 220 to absorb more heat from the thermal component 212. Upon exiting the heat exchanger 220 through outlet port 220d, the heated coolant flows through the thermal conduit system 226 to the heat sink 222. The heat sink 222 absorbs heat from the coolant, returning the coolant to a lower temperature. The thermal conduit system 226 maintains the coolant fluid separate from the phase change material inside the heat sink 222. The path of the thermal conduit system 226 through the heat sink 222 may be straight or tortuous depending on the performance specifications of the temperature management system 210. After exiting the heat sink 222, the coolant flows to the fluid transfer device 228, where it circulates through the temperature management system 210 again.

[0042] The temperature management system 210 removes enough heat to maintain the thermal component 212 at or below its rated temperature~~, which is typically~~ , *e.g.*, no more than 125°C. For ~~example~~ the example above, the temperature management system 210 may maintain the thermal component 212 at or below 100°C, or even at or below 80°C. ~~The~~ Typically, the lower the temperature, the longer the life of the thermal component 212.

[0047] Located in the thermal conduit system 426 is a fluid transfer device 428 for flowing the coolant fluid through the thermal conduit system 426. The fluid transfer device may be located at any suitable location in the temperature management system 410. The fluid transfer device 428 may also be any suitable device for flowing the coolant fluid. By way of non-limiting example, the fluid transfer device may be a pump, such as a mini-pump or a micro-pump. The coolant fluid flowing within the thermal conduit system 426 is ~~in thermal communication~~ thermally coupled with the heat exchanger 420 and the heat sink 422. The coolant fluid may be water or any other suitable fluid.

[0049] As shown in FIGURE 4, the coolant fluid travels from the low temperature heat sink 422 to the heat exchanger 420 where the coolant is ~~in thermal communication~~ thermally coupled with the heat exchanger 420. The heat exchanger 420 is ~~in turn in either direct or indirect thermal contact~~ thermally coupled with the thermal component 412 by conduction, convection, and/or radiation paths. As the coolant flows through the heat exchanger 420, it absorbs heat from the heat exchanger 420, allowing the heat exchanger 420 to absorb more heat from the thermal component 412. Upon exiting the heat exchanger 420, the heated coolant flows through the thermal conduit system 426 and is expelled from the temperature management system 410 as shown by direction arrow 432.

[0054] Located in the thermal conduit system 526 is a fluid transfer device 528 for flowing the coolant fluid through the thermal conduit system 526. The fluid transfer device may be located at any suitable location in the temperature management system 510. The fluid transfer device 528 may also be any suitable device for flowing the coolant fluid. By way of non-limiting example, the fluid transfer device may be a pump, such as a mini-pump or a micro-pump. The coolant fluid flowing within the thermal conduit system 526 is ~~in thermal communication~~ thermally coupled with the heat exchanger 520 and the heat sink 522. The coolant fluid may be water or any other suitable fluid.

[0056] As shown in FIGURE 5, the coolant fluid travels through the heat exchanger 520. The heat exchanger 520 is ~~in either direct or indirect thermal contact~~ thermally coupled with the thermal component 512 by conduction, convection, and/or radiation paths. As the coolant flows through the heat exchanger 520, it absorbs heat from the heat exchanger 520, allowing the heat exchanger 520 to absorb more heat from the thermal component 512. Upon exiting the heat exchanger 520, the heated coolant flows through the thermal conduit system 526 and then through the heat sink 522. After passing through the heat sink 522, the coolant is expelled from the temperature management system 510 as shown by direction arrow 532.

[0063] A temperature management system for managing the temperature of a discrete, thermal component. The temperature management system comprises a heat exchanger ~~in thermal contact~~ thermally coupled with the thermal component. The system also comprises a fluid transfer device that

circulates a coolant fluid through a thermal conduit system. As the coolant flows through the heat exchanger, it absorbs heat from the component. Upon exiting the heat exchanger, the heated coolant flows to the heat sink where the heat sink absorbs heat from the coolant fluid.